HIGH-PRECISION RADIOCARBON DATING OF THE CONSTRUCTION PHASE OF OAKBANK CRANNOG, LOCH TAY, PERTHSHIRE

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ABSTRACT. Many of the Loch Tay crannogs were built in the Early Iron Age and so calibration of the radiocarbon ages produces very broad calendar age ranges due to the well-documented Hallstatt plateau in the calibration curve. However, the large oak timbers that were used in the construction of some of the crannogs potentially provide a means of improving the precision of the dating through subdividing them into decadal or subdecadal increments, dating them to high precision and wiggle-matching the resulting data to the master ^{14}C calibration curve. We obtained a sample from 1 oak timber from Oakbank Crannog comprising 70 rings (Sample OB06 WMS 1, T103) including sapwood that was complete to the bark edge. The timber is situated on the northeast edge of the main living area of the crannog and as a large and strong oak pile would have been a useful support in more than 1 phase of occupation and may be related to the earliest construction phase of the site. This was sectioned into 5-yr increments and dated to a precision of approximately ±8–16 ^{14}C yr (1 σ). The wiggle-match predicts that the last ring dated was formed around 500 BC (maximum range of 520–465 BC) and should be taken as indicative of the likely time of construction of Oakbank Crannog. This is a considerable improvement on the estimates based on single ^{14}C ages made on oak samples, which typically encompassed the period from around 800–400 BC.

INTRODUCTION

Crannogs are artificial islands found almost exclusively in Scotland and Ireland. They were built on open water, clearly separate from the shore, and typically, some sort of timber or stone dwelling place was constructed on them (Dixon 2004). The earliest known crannogs date to the Early Iron Age (in Scotland, the Iron Age is taken to be the period from about 700 BC to AD 500), while historical records show that some were in use as recently as the 17th century (Morrison 1985). Most appear now as submerged or partially submerged piles of rocks or small, tree-covered, stony islands; however, beneath these rocks are often well-preserved timbers and numerous organic artifacts. In Loch Tay, there are the remains of 18 artificial island dwellings (Dixon 2004), and we have currently carried out radiocarbon dating on 13 of them (Dixon et al. 2007). Within that group, it is possible to see divisions, with 9 sites ranging within the period 820–350 BC, 2 within the period 400–50 BC, and 2 from 170 BC–AD 180. The group of 9 all have broad calendar age ranges as a consequence of the Early Iron Age plateau (Hallstatt plateau) in the calibration curve. However, the large oak timbers that were used in the primary construction phase of some of the crannogs potentially provide a means of improving the precision of the dating through subdividing them into decadal or subdecadal increments, dating them to high precision and wiggle-matching the resulting data to the master ^{14}C calibration curve. This would provide a better estimate of the felling time of the timbers and hence the initial construction phase of the crannogs.

The most widely studied of the Loch Tay crannogs is Oakbank, which falls into this Early Iron Age category. It has been subject to excavation for approximately the past 30 yr and evidence points to it being initially constructed as a free-standing pile dwelling with open water underneath the platform. All 9 ^{14}C age measurements that have previously been made, including those on large structural timbers that were proposed to be associated with the initial construction phase, place its construction in the period 800–400 BC (Dixon et al. 2007). It was decided because of the wealth of information that already existed about this site, including observations of large structural timbers,

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that it was the most suited to a first attempt at the wiggle-match approach. Informal evidence from an early tree-ring study had suggested that oak timbers of 100+ yr old had been identified (M Baillie, personal communication); however, in practice, the oldest timber that we could identify and sample (sample OB06 WMS 1, T103) contained only 70 rings but was complete to the bark edge (Figure 1).

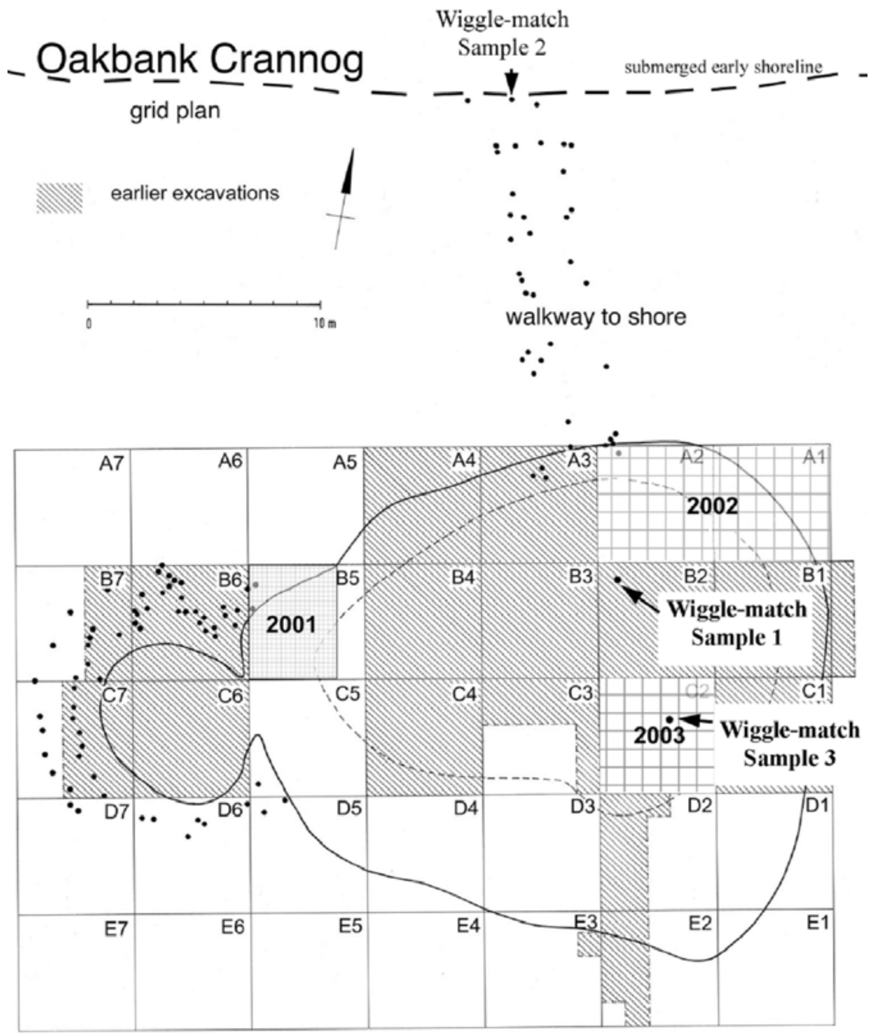

Figure 1 Location of potential wiggle-matching samples on Oakbank Crannog, Loch Tay

METHODS

Timber 103 (T103) was targeted as 1 of 3 potential samples from Oakbank Crannog chosen for wiggle-matching. It was 1 of 2 timbers sampled in 1980 for ^{14}C dating and it produced an age then of 2545 ± 55 yr BP (GU-1323), which calibrates to 820–500 BC at 2 σ (Dixon 1981). The timber is situated on the northeast edge of the main living area of the crannog and as a large and strong oak pile, it would have been a useful support in more than 1 phase of occupation and may be related to the earliest construction phase of the site (see Figure 2).

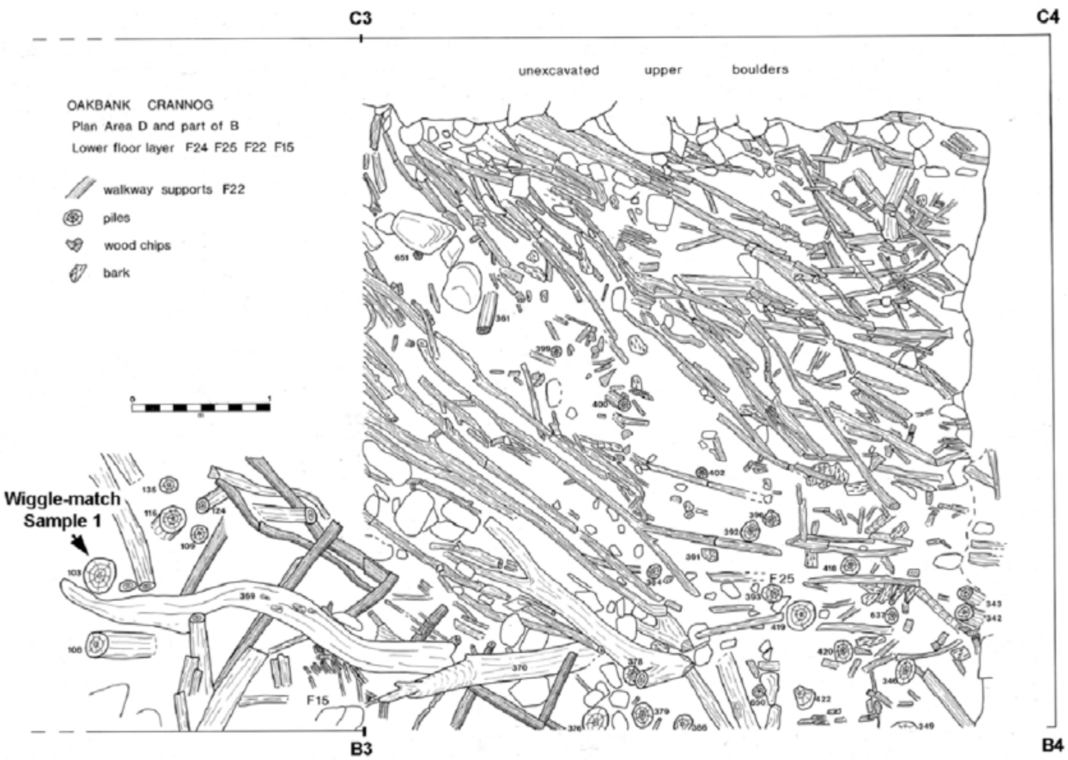

Figure 2 Location of timber (T103) on Oakbank Crannog chosen for wiggle-matching

A section of the oak trunk was cut by a diver using a panel saw and kept in water to prevent drying and splitting. On return to the lab, the sample was allowed to partially dry out to ease identification of the individual rings. The oak was sectioned into 5-yr increments and the samples taken to alpha cellulose using the method of Hoper et al. (1998). Approximately 20–40 mg samples of alpha cellulose were combusted in precleaned, sealed quartz tubes (Vandeputte et al. 1996) and the CO_2 cryogenically purified. We then took 2 aliquots of gas for graphitization according to the method of Slota et al. (1987), thus producing 2 graphite targets per 5-ring span. The first set of 14 samples was measured on our NEC 250kV SSAMS during December 2007 to a precision of around ±8–16 yr at 1 σ. At the same time, we also carried out 10 replicate analyses on an in-house laboratory standard to verify our accuracy and precision. The standard was produced from a bulk humic acid sample and was used in an early intercalibration study (^{14}C Cross-check) and is currently in use within the Fifth International Radiocarbon Intercomparison (VIRI Sample T). It has a consensus value of 3360 ± 3 yr BP (E M Scott, personal communication). This value is completely in line with our own data for this sample when measured to routine precision (mean of 3367 ± 33 yr BP for 25 measurements) during October and November 2007. Our quoted error for routine analysis is ±30–35 yr. We chose the humic acid because the ^{14}C activity is close to that of the crannog wood and because it was absolutely homogeneous in activity, having been through the solution phase.

The second set of 14 samples was measured in March 2008 using our NEC 5MV Tandem AMS to the same precision, and again, we also carried out 10 replicate analyses on the in-house laboratory standard to verify accuracy and precision.

RESULTS

Table 1 illustrates the data for the humic acid in-house standard measured on the SSAMS and demonstrates that the data are accurate (mean value of 3373 yr BP compared to the consensus value of 3360 BP) and that the precision can be justified (the standard deviation on the 10 measurements is approximately the same as the errors on individual measurements).

Table 1 ^{14}C data for the SUERC humic acid in-house laboratory standard.

Sample nr	Humic acid ^{14}C age (yr BP)	1-σ error
1	3389	10
2	3368	9
3	3372	13
4	3367	15
5	3366	10
6	3362	15
7	3368	12
8	3358	12
9	3374	13
10	3406	14
Mean age and std dev	3373	14

Table 2 presents the ^{14}C data for the tree rings measured on the SSAMS. These were incorporated into a model generated in OxCal 3.10 (Bronk Ramsey 1995, 2001) and using the IntCal04 data set (Reimer et al. 2004), to look at the best fit to the calibration curve (wiggle-match). The summary results of the wiggle-match are presented in Figures 3 and 4.

Table 2 ^{14}C ages for 5 ring spans from the oak timber from Oakbank Crannog.

SUERC nr	Ring nr	Age (yr BP)	1-σ error
16224	0–5	2433	11
16225	6–10	2442	13
16228	11–15	2448	10
16229	16–20	2437	11
16234	21–25	2446	9
16235	26–30	2440	9
16238	31–35	2450	12
16239	36–40	2432	9
16244	41–45	2437	11
16245	46–50	2463	11
16248	51–55	2438	13
16249	56–60	2443	19
16254	61–65	2520	14
16255	66–70	2505	13

In the case where combinations of age measurements are being modeled, an agreement index is calculated in which there is a threshold similar to the 5% χ^2 test. The program will indicate if the agreement is poor. The value A is the calculated agreement index and An is the value (dependent on n, the number of samples analyzed in the sequence) below which it should not fall. In Figure 3, $A = 55.5\%$ and $An = 18.9\%$, indicating a satisfactory degree of agreement.

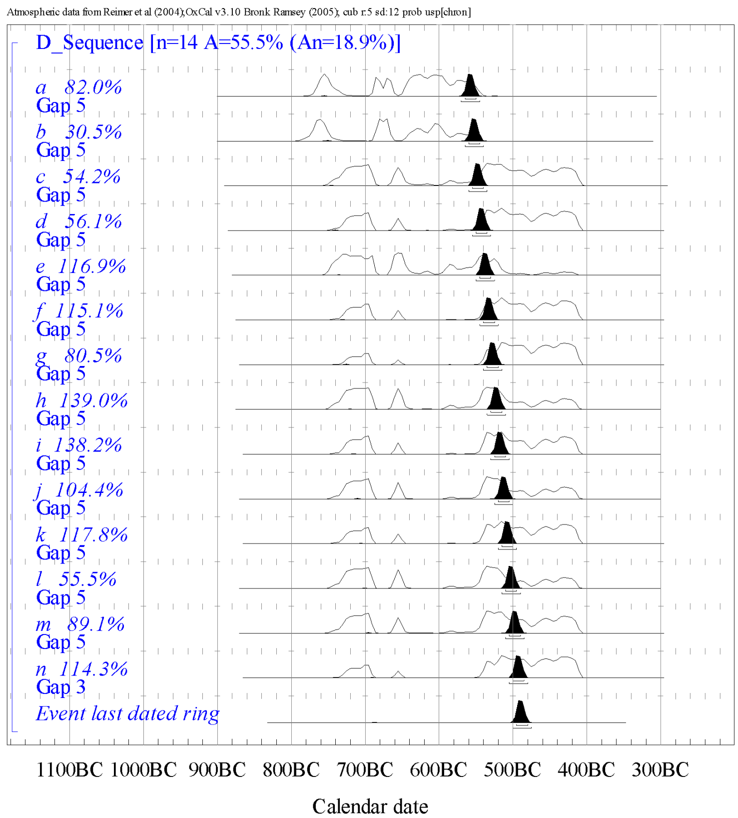

Figure 3 Probability distributions for a series of 14 wood samples, each comprising 5 rings, taken from an oak timber forming a part of the construction of Oakbank Crannog.

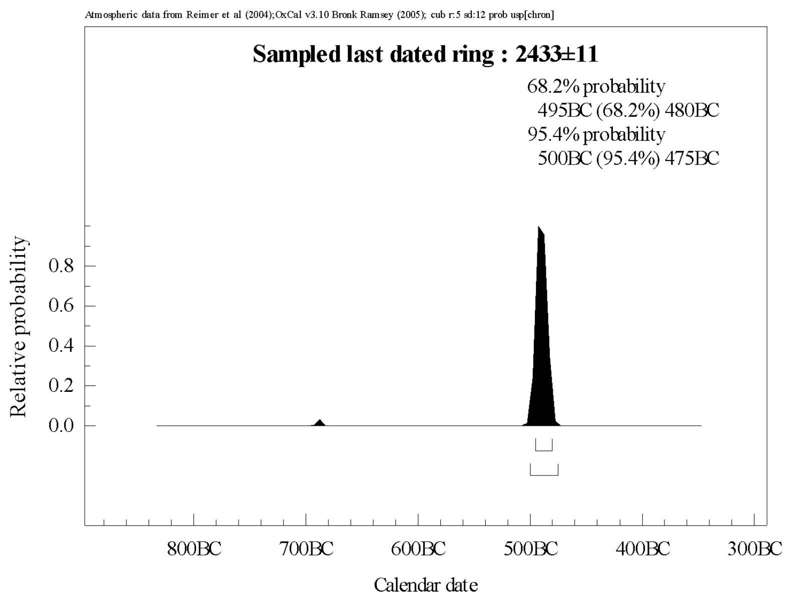

Figure 4 Posterior density estimate for the last ring dated

Figure 4 is the posterior density estimate for the last ring dated and indicates a 95.4% probability that the ring was laid down during the period 500–475 BC.

One feature of the data in Table 2 for the tree-ring sequence was that the last 2 increments of 5 rings gave ages in excess of 2500 BP while the remainder were all between 2432 and 2463 BP. This could be real; however, the AMS did develop a fault just before these samples were measured and so this could have led to a small offset in the data when the samples were measured some time later, although there is no great evidence of this in the data for the humic acid standards.

The data for the second set of targets, measured using the 5MV Tandem AMS, are given in Tables 3 and 4. Again, the humic acid data (Table 3) show excellent agreement with the consensus value and a standard deviation that is in good agreement with the errors on individual measurements. This time, the tree-ring data do not have the same pattern of 2 ages in excess of 2500 BP. Again, a wiggle-match was performed on the data and the results are illustrated in Figures 5 and 6. The results indicate that the last ring dated was laid down between 520 and 470 BC. However, the level of agreement is poor (A = 4.5%, An = 18.9%).

Table 3 ^{14}C data for the SUERC humic acid laboratory standard measured with the second batch of samples.

Sample nr	Humic acid ^{14}C age (yr BP)	1-σ error
1	3382	10
2	3359	13
3	3369	12
4	3350	17
5	3361	11
6	3351	14
7	3375	14
8	3394	12
9	3376	12
10	3374	11
Mean age and std dev	3369	14

Table 4 ^{14}C ages for the second set of 5 ring spans from the oak timber from Oakbank Crannog.

SUERC nr	Ring nr	Age (yr BP)	1-σ error
17379	0–5	2377	11
17380	6–10	2469	12
17383	11–15	2471	10
17384	16–20	2421	11
17389	21–25	2457	15
17390	26–30	2445	12
17393	31–35	2473	11
17394	36–40	2473	12
17399	41–45	2451	13
17400	46–50	2479	12
17403	51–55	2473	13
17404	56–60	2457	14
17409	61–65	2444	13
17410	66–70	2436	11

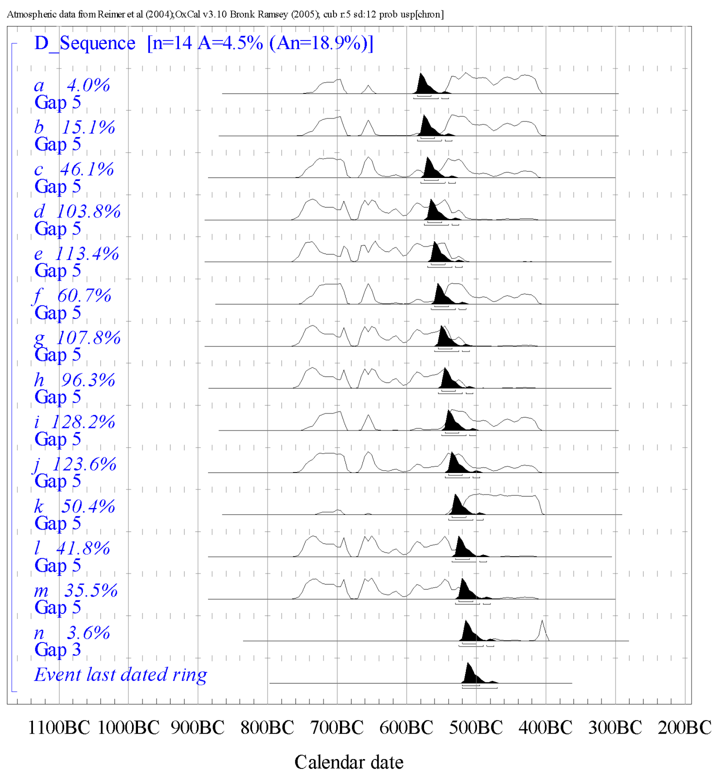

Figure 5 Probability distributions for the second series of 14 wood samples, each comprising 5 rings, taken from an oak timber forming a part of the construction of Oakbank Crannog.

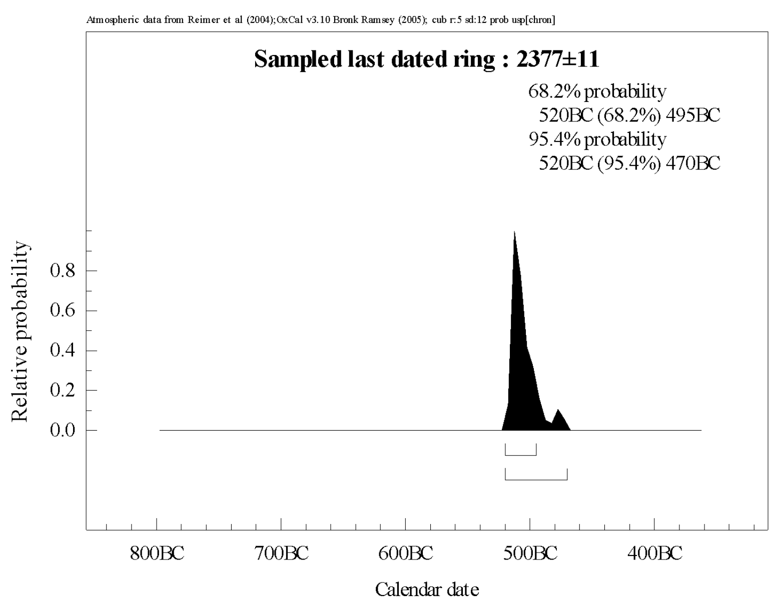

Figure 6 Posterior density estimate for the last ring dated for the second batch of samples

While the humic acid standard data for the 2 sets of analyses are in excellent agreement, there are larger discrepancies than would have been expected between the first and second batch of tree-ring data for certain samples. This implies that this excess variability is either derived from the individual graphite preparations or from fractionation during measurement. $\delta^{13}C$ values for fractionation corrections are made off-line and do not take into account any fractionation occurring during the measurement process (see Naysmith et al., this volume). While this appears to be valid for the vast majority of samples and probably all that are measured at routine precision (±30–35 yr BP), it may be that it is not valid for a small proportion of the high-precision measurements. These are factors that will require further examination.

Finally, the data from the 2 batches of targets were combined and the larger of the weighted mean error or standard deviation was taken for each pair. The exception to this was for the pairs that included the 2 ages in excess of 2500 BP. Here, only the ages from the second batch were used. These data are given in Table 5. A wiggle-match was again performed and the results are illustrated in Figures 7 and 8. This time, the last ring dated is calculated as having been laid down between 500 and 465 BC and the level of agreement is satisfactory (*A* = 25.6%, *An* = 18.9%).

Table 5 ^{14}C ages for the combined data set of 5 ring spans from the oak timber from Oakbank Crannog.

Lab nr	Ring nr	Age (yr BP)	1-σ error
15702	0–5	2405	28
15703	6–10	2457	13
15704	11–15	2460	12
15705	16–20	2429	8
15706	21–25	2449	8
15707	26–30	2442	7
15708	31–35	2462	11
15709	36–40	2447	20
15710	41–45	2443	8
15711	46–50	2470	8
15712	51–55	2456	18
15713	56–60	2452	11
15714	61–65	2444	13
15715	66–70	2436	11

CONCLUSION

Although the agreements in probability between the individual measurements and the wiggle-match model are not always good, all 3 calculations predict that the last ring dated was formed around 500 BC (maximum range of 520–465 BC, based on all 3 calculated ranges) and should be taken as the likely time of construction of Oakbank Crannog. This is a considerable improvement on the estimates based on 9 single ^{14}C ages previously made on oak samples, which typically encompassed the period from around 800–400 BC (Dixon et al. 2007). While this study is based on a single oak timber, it demonstrates the potential for overcoming the broad calendar age ranges produced by dating single samples. To provide convincing evidence that the results relate to the primary construction phase of Oakbank Crannog, it will be necessary to undertake further wiggle-matches on large structural timbers for confirmation of this result. There was excess variability in a small number of pairs of data for which the likely causes are differences associated with (i) the graphitization process or (ii) fractionation during measurement. These factors will require further investigation. The next

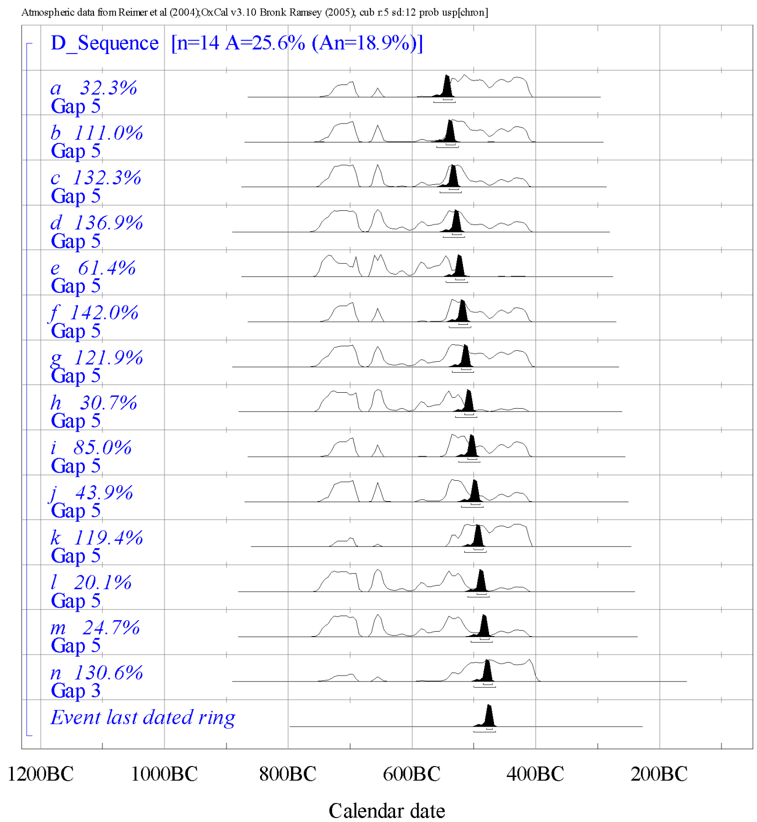

Figure 7 Probability distributions for the combined data set of 14 wood samples, each comprising 5 rings, taken from an oak timber forming a part of the construction of Oakbank Crannog

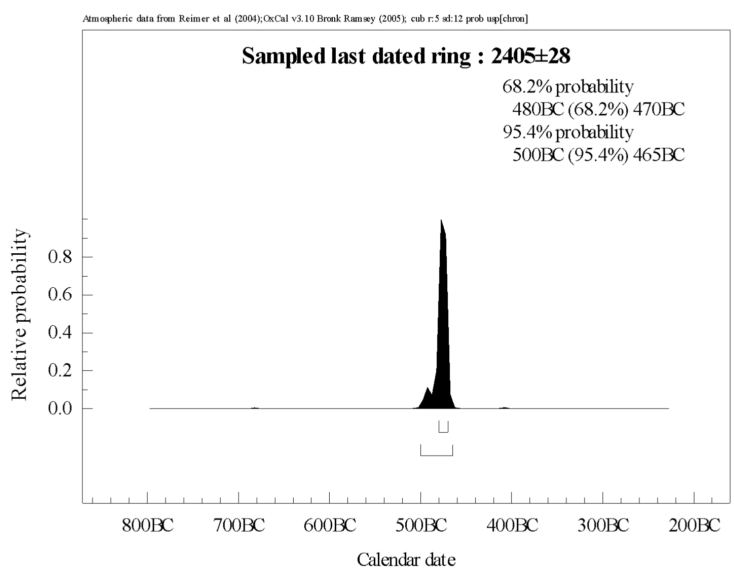

Figure 8 Posterior density estimate for the last ring dated for the combined data

stage in the research will be to carry out a similar study on further timbers from Oakbank and other crannogs. Obtaining similarly sized timbers from other crannogs may not prove possible; however, there is the possibility of achieving similar results with shorter ring sequences. The basic idea is that it is possible to get "high-precision" estimates from a couple of short ring sequences and a few outer 5-yr blocks (D W Hamilton, personal communication). The ultimate aim is to look for synchronicity in the building of the Early Iron Age crannogs within and beyond Loch Tay to aid studies of how this area of Scotland became populated during the Iron Age.

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